Instruments of Science: their social dimensions

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This is the text of an evening talk given on 3rd March 2009 in the University of Aberdeen. The talk was illustrated with PowerPoint slides, each of which usually contained several images. I have included here a single thumbnail image from most slides, to suggest the illustrations. The talk was also accompanied by a small display of instruments from the Natural Philosophy Collection that illuminated some of the points made.

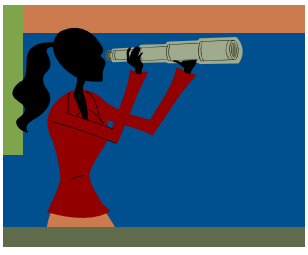
Introduction

I've seen a great many historic scientific instruments over the decades, in many collections, and can certainly vouch for the fact that the University of Aberdeen's collection is rich by any standards. The collection has an obvious relevance to various aspects of the history of science and technology but it also has cultural relevance that is often undervalued. Cars may be built by robots in factories but science has always been carried out by people, people deeply embedded in the culture of their times. Today, science is more embedded in society than ever before. A day after Barack Obama was inaugurated in January of this year, the Speaker of the House of Representatives was interviewed about what the new plan was to revive the US economy. She replied: "*SCIENCE, science, science and science*". In a way, then, it's topical to look at some of the social dimensions of instruments of science.

The title of my talk doesn't give much away. Interesting journeys often have an element of surprise and I'm not going to give the game away by following the rule book of telling you where we are going, except to say that I'll discuss various inter-relationships between scientific instruments and society. The subject is potentially a very big one so mine is a personal choice of specific examples to illustrate more general points.

The iconic telescope

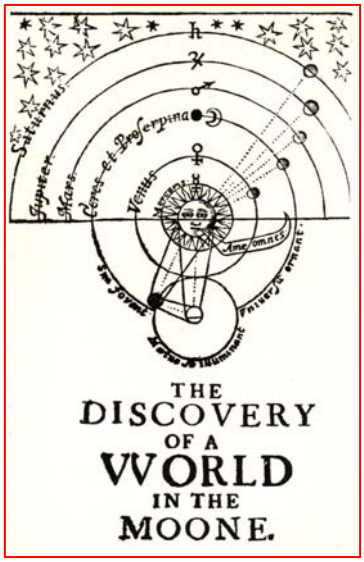
2009 is the 'International Year of Astronomy', declared as such in a United Nations General Assembly, celebrating 400 years of the telescope as a scientific instrument. I was thinking of this recently so what better than to begin with the telescope as an instrument that illustrates a number of the ways instruments have impacted on society.



No-one needs to be told what a conventional telescope looks like: it has an iconic shape. A clip-art drawing of a person looking through a telescope immediately conjures up the thought of someone peering into the distance.

Dreams of seeing afar

The first impact of the telescope was the impact of the idea itself. Once the concept that a real instrument could be made that allowed one to see more clearly objects at a distance then people's imaginations expanded into a new realm. Distance was suddenly no barrier to seeing. It was imagined that people could be seen leagues away, ships in the offing clearly identified, armies seen in detail when they were scarcely visible to the naked eye, etc. Imagination wasn't constrained by the reality of performance. The telescope was described as



an item of 'natural magic', almost on a par with the crystal ball, the difference being that the crystal ball allegedly gave those who could see with it a picture of a distant time whereas the telescope gave one a picture of distance space. [*The illustration is from John Wilkins, 1638*]. Reality was of course very different. The very early telescopes gave an unclear image by modern standards, with a magnification of about 3. As the 17th century wore on their performance improved but reality sank in, dreams of amazing visions of distant worlds faded.

What makes an instrument scientific?

400 years ago, distinctions between reality and imagination were much less easily made than today but even today it is not uncommon for new inventions to be credited with much more ability that they really have. If these aspirations are confined to fiction that's fine. Just think of the holodeck, or warp-speed travel, instant transporter capability and so on that various Star-Trek series use, all with scientifically based jargon to describe them. Entertaining fiction. However, there are plenty of examples in real life of alleged scientific equipment being employed to do something it doesn't really do.

One example was highlighted in a recent consumer program on TV. This is a digression from telescopes but it makes a valuable point. The K-test meter is I believe a bogus instrument that will relieve you of £25 or £30 for an alleged measure of your intolerance to certain kinds of food. The instrument is in use in a chain of pharmacy stores in England. So far the Scots have been spared the apparent deception but there is a real issue here. How do you know that an alleged scientific instrument does measure what it claims to? The bottom line is the way science works. Scientific knowledge is both public knowledge and is testable knowledge. A scientific instrument that you can trust will have publically accessible descriptions of the principles involved, using internationally recognised language in its proper context; an explanation of the reason why it works; the tests that demonstrate it does work, and that it will respond consistently to the stimulus, or property it is intended to measure. The K-test meter fails on almost all of these counts. Art maybe anything you care to call art. A scientific instrument is not anything you care to call a scientific instrument. You'd probably expect me to say this as retired lecturer in science but those most easily taken in are those with little scientific background. Some knowledge of how things work, and how nature works, is valuable knowledge in today's society. It would also have been valuable 400 years ago but comparatively little knowledge was then available.

Telescopes have changed humanity

I started this line by commenting that telescopes had impacted society by creating expectations, expectations that weren't fulfilled in reality. In a more subtle way, telescopes have contributed

to a real change in the way we all think of ourselves and human-kind at large. Over 400 years, knowledge gained from using telescopes has completely changed the perspective we have of ourselves in the Universe. 400 years ago, the Earth was perceived at the centre of the Universe, a Universe that was created less than 6000 years earlier with 5 planets, the Sun, the Moon and about 2000 visible stars for company. Thanks to the telescope, and to lots of interpretative thought on what it has revealed, that view has been completely swept away. The Earth isn't at the centre of anything; the Universe is known to be some 13.7 billion years old, the Earth about 4.6 billion years old; there is a lot more in the solar system than 5 planets and more stars in the sky than grains of sand on the Earth. In the 'International Year of Astronomy' it's appropriate to reflect on the impact that the telescope has had in changing our notion of our place in the Universe. No instrument has made it clearer that humanity has '*an intimate connection with the entire cosmos*', as Lawrence Krauss wrote recently. [*The illustration shows the modern Gemini North telescope mirror*].

17th century telescopes

The telescope also introduces another theme: the relationship between instrument and objects one expects to find in a given era. The classic scientific instrument is a construction of wood, brass and glass. That doesn't mean to say that all instruments are like this, or that they don't have the imprint of their age on them. Early telescopes may have been poor on performance but many were strong on ornamentation. 2 lenses in a pasteboard tube doesn't sound like a desirable object for an aristocrat, Cardinal or military commander but wrap the tube in vellum and add fine gold tooling and any 17th century VIP would be pleased to accept it. You will see these productions in several scientific instrument museums. [*The illustration is courtesy the IMSS (Istituto e Museo di Storia della Scienza) in Florence*].

Usefulness & prestige

By the end of the 1600s the telescope had developed into its recognisable iconic form of a device with several co-axial sliding tubes that could be compacted for storage or extended for use. The telescope did achieve some of the hoped for military usefulness, particularly in the navy. Indeed, it became a desirable prop in prestige naval portraits. However, by modern standards the image was poor, suffered from spurious prismatic colouring and the field of view was small. *[The illustration is a portrait the Honourable William Kerr, courtesy of the National Maritime Museum].*

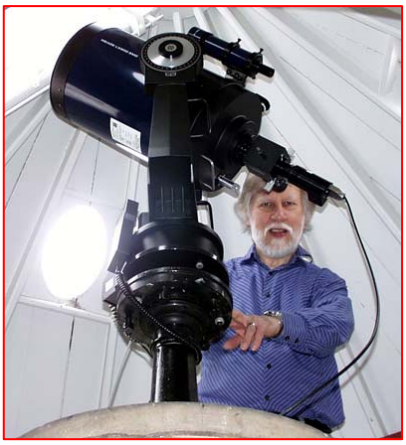
18th century telescopes

Come the 18th century, the gentleman astronomer would have seen items on the last slide as 'very last century'. The 18th century prince or gentleman wanted a highly polished brass instrument on a nice tripod stand that would set off his library. In this century reflecting telescopes, where the main imaging component is a mirror and not a lens, became the must-have version. They were pretty free of spurious colouring. In fact, the problem of spurious colouring of the images from lens telescopes was largely solved in the late 1750s. [*Illustration shows a telescope by James Short, courtesy National Museums of Scotland*].

19th century telescopes

The 19th century amateur star-gazer wanted an instrument with larger lenses that could see fainter objects, an instrument that he could wheel out onto the patio of his country house. By this time the professionals were building seriously big instruments. [*Illustration of Ross telescope circa 1850, University of Aberdeen*].

20th century telescopes



The 20th century amateur has come back to the shorter, more manoeuvrable instrument, often equipped with optics that weren't available in the previous centuries and, over the last couple of decades, computer control. The brass tubing has gone, being replaced by moulded plastic and anodised aluminium; the brass scales have given way to electronic digital read-outs. [*Illustration: author at the University of Aberdeen's Meade LX200*].

One final point I'm going to draw from the example of telescopes is that to make instruments you need raw material, tools, highly technical expertise and *other instruments*. One reason why 20th century telescopes are much better than their predecessors is that their optics and mechanics are designed and tested to much higher precision than their predecessors. The ability of modern instruments to test mechanical surfaces for flatness and roundness and relative location to fractions of a micron (a millionth of a metre), indeed to nanometres (a millionth of a mm) has been behind a huge variety of modern products besides telescopes. I'll cite as three examples: modern efficient car and aeroplane engines, video recorders and modern electronic fabrication techniques.

17th century microscopes

Scientific instruments are usually judged by their functionality and to some extent what the users do with them or discover with them. We don't tend to associate style and

ornamentation with them but these concepts certainly apply. Possibly the most successful scientific instrument **ever** has been the microscope, the number-one research tool of biology and medicine. It wasn't just professionals who used microscopes. For example the Aberdeen Microscopical Society thrived in the 19th century, as did many similar societies all over the country. Look at historic microscopes and you'll see a parallel trend to that shown in telescopes, as the accompanying 3 slides show.

In particular, the shark-skin covered or tooled leather productions of the 17th and early 18th centuries gave way to the brass productions that took over from mid 18th century. Ornamentation is a feature of pre-20th century scientific equipment, ornamentation ranging from the quiet to the ostentatious. You might have expected early instruments to be plain and simple and later ones to be more ornamental on the grounds that making things became easier and hence there was more time to add ornamentation. On the whole that isn't the case. Ornamentation is conspicuous in early instruments. [*Illustration of a Culpeper microscope with sharkskin outer tube and gold embossed inner tube, University of Aberdeen*]

18th century microscopes

Indeed ornamentation appears as a substitute for performance, as a means of puffing up the apparent importance of the piece. Ergonomically, early microscopes are a disaster. For example, you strain your neck looking into an upright instrument for any length of time, the focusing mechanism is crude, there is no easy facility for swapping different powers of objectives, there is no binocular viewing. 200 years after the invention of the device they were still mechanically and indeed optically quite primitive, but some of the ornamentation was terrific. [*Illustration of an instrument in the George III collection, courtesy Science Museum*].

19th century microscopes

Only in the 19th century did the microscope begin to achieve what the instrument is capable of. I'm not saying that functionality should displace any concerns about appearance but come-on, taking more than 200 years to develop the potential of the microscope seems a bit much to me. [*Illustration of binocular microscope from University of Aberdeen*].

An article in a very recent New Scientist reminded me that the lessons of history are not always learnt. The article discussed how post-war car manufacturers were very reluctant to include proven safety features in their cars in spite of the road death toll in the States reaching 50,000 per year. One Ford engineer was quoted "*This company is run by salesmen not engineers.*

The priority is styling, not safety". 50,000 lives annually is a high price to pay for raising styling above safety.

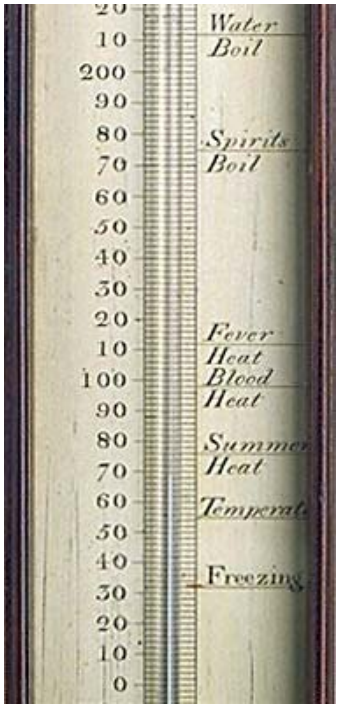
I've used telescopes and microscopes as an example, but my general point here is that scientific instruments are not anonymous pieces of technology but they have the imprint of society upon them.

The seven pillars of measurement

It was the great Scottish physicist Lord Kelvin who once famously said "*I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind."* Numbers are at the heart of a lot of science. Numbers mean measurement. There is, more or less, one system of measurement used internationally in science, the SI system ('Le Systême International') or, as it's often known, the mksA (metres, kilograms, seconds, amps) system. In this system there are 7 fundamental quantities and the rest are derived from them in one way or another. Corresponding to each of the fundamental quantities and to all the derived quantities there are scientific instruments of measurement, usually a great many in fact. Measurement underpins all modern industry and the corresponding wealth creation and so scientific instruments in great numbers impact on society through industry. I could select many examples but I've chosen to comment on temperature.

Thermometers

Thermometers are one of the few scientific instruments that have become part of everyday life and current concerns about global warming past and future have made them an important part of a modern debate. Climate records of the past were clearly made using thermometers of past-times and not present day instruments. How far back in time can we go? Were early readings any good? The earliest devices simply indicated temperature change without having a calibrated scale and are better called thermoscopes. The version on the left of the slide alleged to go back to Galileo and a number of other 17th century ideas were too inaccurate or bulky or fragile to form a convenient meter for measuring temperature, a meter that was portable, versatile, cheap, reproducible, reliable and all you expect from a thermometer. Who founded modern thermometry?

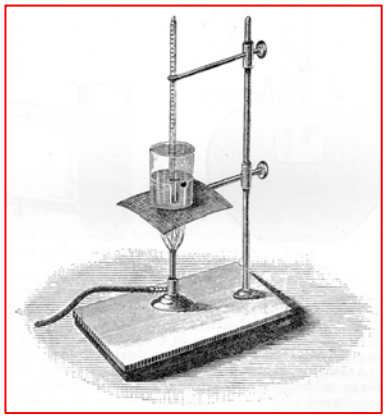


The Fahrenheit scale pre-dated the Celsius scale. Daniel G. Fahrenheit (1686 – 1736) spent his early life in Gdansk in Poland but lived in The Netherlands for most of his adult life, earning a living mainly as a thermometer and barometer maker. He invented the mercury-in-glass thermometer in 1714 and worked on his scale with 180 divisions between the freezing and boiling point of water over the following decade. [180 divisions was a natural and useful choice. For example, people had been dividing directions, from one direction to its opposite, into 180 degrees for millennia and the range of 180 is divided in parts exactly by 2, 3, 4, 5, 6, 9, 10, 12 ….. and other integers]. What made Fahrenheit's thermometers particularly notable in his day was that they were consistent, unlike the slightly earlier spirit of wine thermometers

that tended to vary, in part because the alcohol used was a variable mixture of alcohol and water. Fahrenheit sold many thermometers as a valuable aid to doctors, one of the few innovations in medical practice in the early 1700s that was effective and would still appeal to anyone today. Fahrenheit's scale was quickly taken up in Britain as well as The Netherlands, and later spread to America and British colonies.

Impact of thermometers

Imagine the impact of being able to supply good thermometers into a world that didn't really have them. The new thermometers of the 1700s were taken all round the world. One result was that people who lived in temperate climates like ours found that when you measured the temperatures in the tropics, they weren't as sweltering as personal experience suggested; when you measured the temperatures in cold parts of the world, they weren't generally as frigid as had been imagined. People realised that plants from hot parts of the world could indeed survive in glass houses in countries like Britain and Holland, and so began the eighteenth century passion for collecting plants from all over the world and growing exotic species. Botanical knowledge blossomed, to make an appropriate analogy. So did a wide range of chemical activities. Many chemical reactions depend sensitively on temperature. Once you have good thermometers, then you can have accurate control over what you are doing with chemical reactions, in industry and in daily life. Imagine cooking in an oven without having much of an idea of the oven's temperature. Quality control improved in the brewing industry and many other industries besides. Many properties of matter depend on temperature, like melting and freezing points, viscosity, expansion and contraction and much more. A lot of science needs a thermometer. Indeed, without the thermometer, meteorology would not be a science.



If you reflect on it, the basic laws of optics, mechanics, planetary motion and so on were discovered in the 17th century but not the basic laws of science that involve temperature. These were 18th and 19th century discoveries, because the thermometer as a tool of science was a later invention. We don't tend to think of the humble liquid in glass thermometer found in almost every house as a sophisticated instrument but it came on the scene a lot later than mechanical clocks, microscopes, telescopes and a good number of other scientific instruments. Pause when you next see one and reflect what an elegant, simple but effective device it is.

Celsius

In the early days of thermometry there were almost as many scales as there were inventors and improvers in the field. A Swedish Professor of Astronomy, Anders Celsius (1701 - 1744), developed his alternative scale not long after Fahrenheit's work. The Fahrenheit and Celsius scales emerged as the survivors. Then the world had two different devices to do the same job – a bit like the videotape scenario facing Betamax and VHS in the early days of electronic video recording, or the recent clash between Blu-ray and HD DVD. Although Fahrenheit was the more inventive pioneer, his scale is surely doomed to become a historical curiosity in future.

200 years of thermometers

To bring the thermometer story up-to-date, a variety of specialist thermometers were developed for meteorology, such as the ones shown on the left of the slide, and indeed for many other applications. The mercury-in-glass thermometer and the alcohol thermometer that I would have said were both iconic in my youth have been superseded, like many other artefacts of my youth. The dial thermometer was common a few decades ago but now one sees little else other than digital thermometers. The important change as far as the science of thermometry is concerned came in 1990 with the adoption of the platinum resistance thermometer as the standard device for temperatures between about -260ºC and +960ºC. Glass thermometers are history (as are the so-called fixed points of the freezing and boiling point of water that Fahrenheit and Celsius used). [*Illustration shows a 19th century solar radiation thermometer at the University of Aberdeen*].

Collectors

One way of noting the penetration of scientific instruments into society is to ask what instruments have attracted the attention of collectors, not museum collectors but members of the general public? Laboratory instruments, the majority of scientific instruments in fact, don't feature on collectors lists. They are too specialist and usually too rare. Leaving aside globes, clocks, cameras, radios, and technological objects developed especially for society, then microscopes, barometers and navigating & surveying instruments feature strongly in the world of instrument collectors. Thermometers are conspicuously absent, perhaps because they are structurally simple, hardly changing over the centuries and as items to spend your time and money on, comparatively dull. Barometers, though, are definitely a scientific instrument that has penetrated widely into society, particularly since the early 19th century, for a good reason: they genuinely do enable better weather predictions to be made.

Barometers

Barometers certainly came from science to society. The name associated with their invention is Evangelista Torricelli: the date, the early 1640s. To be more precise, what Torricelli showed was that a column of mercury in a glass tube rose and fell with changes in atmospheric pressure. He didn't devise the fully formed instrument with its casing, scale and some important details that it's necessary to get right before you have a decent instrument. However, his pioneering work has long been recognised and even resulted in a unit of atmospheric pressure being named after him, the *torr*, which is only just going out of fashion. [*Commemorative statute in Florence to Torricelli, photo JSR*].

Public barometers

Barometers as instruments developed from the 1680s onwards. They started to become household items in the early 19th century, obviously initially in well-to-do houses but it was

the second-half of the 19th century when they seriously penetrated society. Admiral Fitzroy was significantly responsible, he who as a Captain took the Beagle round the world with Charles Darwin and crew. Fitzroy became convinced that the barometer had real weather predicting power. He promoted their use, designing one especially for weather prediction [*University of Aberdeen instrument illustrated*], and indeed promoted a government-funded scheme where fishing towns were given a public barometer so that fisherman might better know when conditions were unfavourable for setting out. Many lives have surely been saved by this initiative, and not just fishermen's lives, for the toll of sailors of all kinds drowned at sea in the 19th century was horrific.

Aberdeen University 19th century barometers

The University has a good collection of 19th century barometers. The most straightforward design is the 'cistern' barometer, which has a cistern of mercury at the base and a scale near the top on which the level of the mercury meniscus at the top of the column is read. For everyday purposes, the recording of pressure in mm of mercury (the height of the column) or inches of mercury is quite sufficient. To obtain the atmospheric pressure in proper pressure units (Pascals these days), a fundamental but straightforward multiplication involving the density of mercury and the strength of gravity is needed. That's all. Mercury cistern barometers are therefore a standard instrument against which others are calibrated. Observatories and laboratories that need to know atmospheric pressure accurately will use a mercury cistern barometer. I've no doubt that today they cost a small fortune. [*The illustration shows a 19th century observatory instrument form the University of Aberdeen*].

For public use, mercury barometers haven't been made for a century or more. The now classic banjo design originated with a J-shaped tube of mercury and a contraption that floated on top of the open end of the mercury column in the short section of the J and, through a wheel, activated a circular dial needle so that no direct reading of a meniscus was needed. In the mid 19th century the aneroid barometer was developed, dispensing with the mercury altogether and using the expansion and contraction of a sealed bellows displayed via a lever mechanism and pointer to show pressure changes. These changes are still shown in 'mm of mercury' or 'inches of mercury'. The banjo design was carried on but gave way to more compact instruments. [*Illustration shows a mercury banjo barometer from the University of Aberdeen Collection*].

Part of the necessary conditions for the popularity of an instrument is that there are people around who will make them. We are all familiar with the Italian ice-cream makers who seemed to come to every town in the first half of the 20th century. In Aberdeen, many remember the names of Canali and Marchini, though here the Italian ice-cream cafés tended to be given non-Italian names like 'The Washington', 'The Rendezvous', 'The Holburn Café', 'The Kit Kat'. By mid 19th century,

Italian barometer makers seemed likewise to be in every town. The names Altria and Stophani come to mind for Aberdeen. I've not seen this piece of social history written up but it appears that there was an exodus from northern Italy of skilled glass blowers early in the 19th century, almost certainly driven by Napoleonic campaigning and some accompanying intolerance.

Barometers became so commonplace that the word 'barometer' is used as a synonym for something that indicates change. 'Skirt lengths are a barometer of changing fashion', etc.

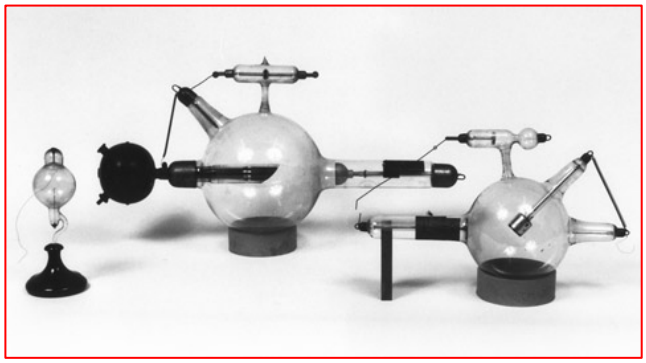
Scientific instruments at large

Although rulers, balances and clocks are fundamental scientific instruments (the mks pillars of the measurement system) and have been developed to exquisite precision in science they were instruments in society long before science as we know it was developed. Passing over these, what else have we come to expect to encounter in everyday life? In terms of measurement, the electricity meter to measure power consumption [*illustrated from the University of Aberdeen collection*], the pressure gauge to measure tyre pressures, perhaps the water meter to measure volume used, light meter to control the exposure in our cameras, the speedometer in our car. When all's said and done, as individuals we don't spend much time measuring but as a society, measurement underpins a huge amount of what we do.

I wanted to spend a little time on how important scientific instruments are to life today. How do we know that the petrol pump delivers exactly the quantity its says and that we are charged for; the supermarket sells us the weight of meat or vegetables it claims, the pressure in our tyres is what the forecourt gauge says or the colour of warning lights is recognizable the same in Bristol and Brechin? Safety may be at stake as well as honesty and the law. It's all to do with standards.

In Britain, practical standards for all physical quantities are kept by the National Physical Laboratory (NPL). **Every worthwhile physical measurement in this country must be traceable back through a series of calibrations to NPL standards.** To achieve this across the country, NPL originally set up the National Measurement Accreditation Service (NAMAS) that authorised accredited laboratories around the country to test particular kinds of measuring instruments. The service is now run by a newer body UKAS (The United Kingdom Accreditation Service). UKAS certified labs are accredited to test specific measurements only, e.g. volume measures of particular kinds such as are used to sell petrol, alcoholic drink, etc., length measures, ranging from those used in surveying to those use for high precision measurements in mechanical workshops; electrical measurements made by typical digital multi-meters, sound measurements, light levels, pressure gauges for industrial and off-shore work and so on and so on. UKAS underpins the whole of British manufacturing and industrial operating. UKAS keeps wealth creation going in this country and this pays for the food on our table and what money we have in our pockets. Everyone should know about it. UKAS is nothing without the NPL standards in the background, the instruments in its accredited laboratories, the instruments of itinerant inspectors and, indeed the instruments that control industries of all kind at the sharp end.

Medical instruments



I want to mention just 3 other topics. The first is 'medical instruments'. In academic circles, medical instruments tend to be categorised separately from 'scientific instruments' but in fact they are instruments of science applied to medicine. Making a huge generalisation, medicine used to be a matter of herbology and leeches. It then became largely biochemistry and surgery. Now the place you're most likely to meet high-tech scientific instruments as a member of the general public is a hospital. Scientific instruments as a name covers not only measurement tools in the strict sense of the word but also apparatus for doing things like imaging. The telescope and microscope were good examples of imaging tools. New medical imaging techniques go back to the discovery of X-rays by Röntgen in 1895, which were very quickly exploited for medical purposes. [*Illustrated, early X-ray tubes from the University of Aberdeen collection*]

Medical imaging

By mid 20th century ultrasonic imaging had come along and now we have gamma-camera imaging and PET imaging [*Illustrated, University of Aberdeen PET scanner*], two techniques based on nuclear physics principles, a new version of X-ray imaging in CAT scans and a subject that's big in Aberdeen, MRI. These big imaging devices all work rather well and that has posed serious problems in the health industry because they are expensive devices. They are, by any standards, very successful scientific instruments that have had a big social impact. In a sense, gene sequencing machines are scientific instruments producing an image and they will have an impact far greater than the diagnostic machines I've just mentioned. Less conspicuous but very valuable on a daily basis are the large number of specialist instruments in medical laboratories that are used for medical tests. It would not be difficult to make a case using medical examples alone that scientific instruments have had a big impact on society.

Scientific instrument makers

If you look through Diderot's great Encylopédie of the mid 18th century you will find illustrations of the work of very many professions of the time, even minority crafts from button-makers through purse-makers to wig-makers. I've found no detailed description of scientific instrument makers. They did exist in the 18th century, and earlier. England, Holland and France were the main production countries but particular England, and more especially London. The volume of their business steadily increased in the 18th century. At home serious gentry invested heavily in scientific past-times; England's naval and military supremacy led to a rapidly expanding empire abroad with a particular demand for navigation and surveying instruments; Universities started teaching natural philosophy by demonstration

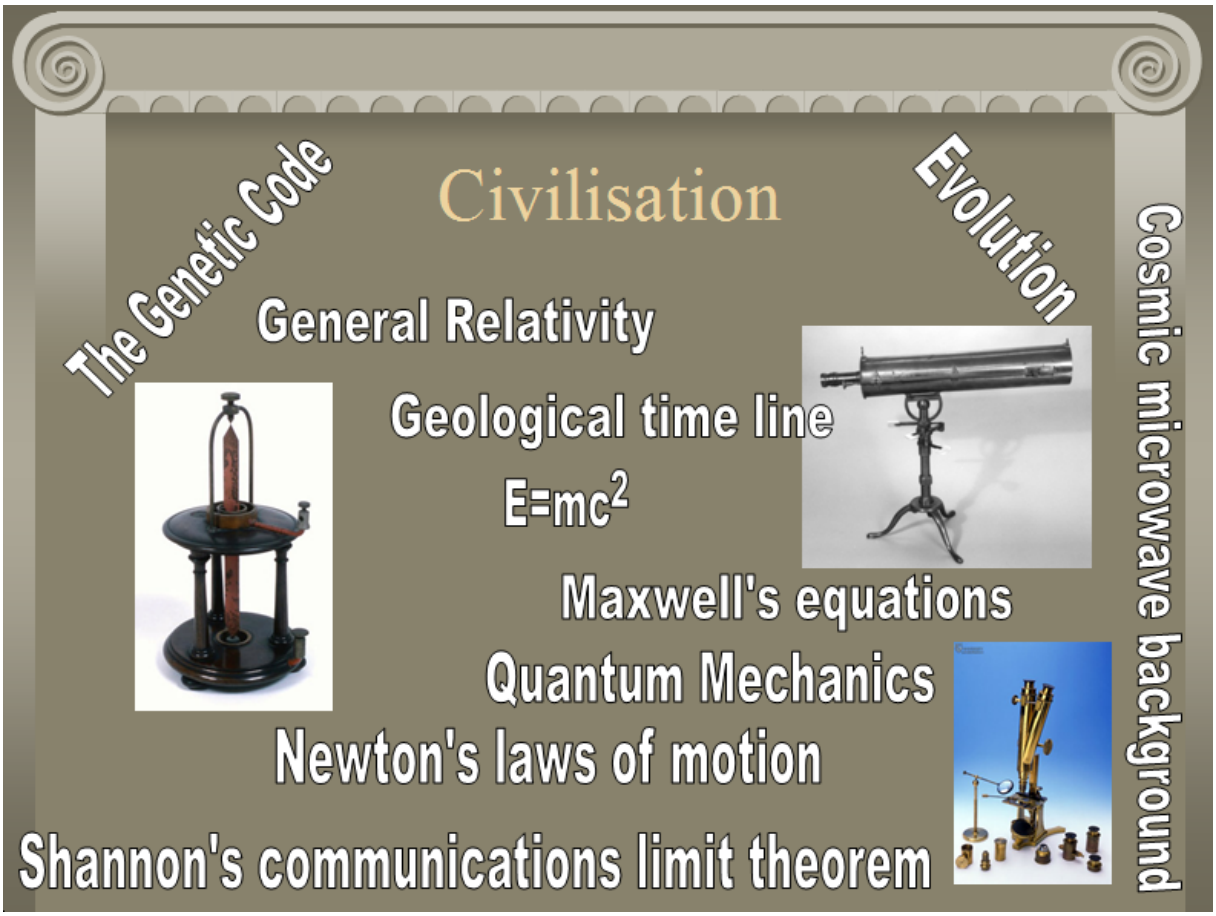
rather than mere rhetoric; more observatories were established and existing ones were re-equipped. Abroad in America, in Europe and in the new colonies demand grew for similar equipment. Scientific instrument making in England lead the world and the supporting technical skills base in the country was considerable. Then they stumbled. As the 19th century writer Agnes Clerke put it: "*But with the opening of the nineteenth century, the almost unbroken monopoly of skill and contrivances which our countrymen had succeeded in establishing was invaded, and British workmen had to be content to exchange a position of supremacy for one of at least partial temporary inferiority.*"

These days 'The government' is often blamed for the woes of industry. In this case they were rightly blamed for tying the shoelaces together of the scientific instrument trade. John Dollond, a London maker, had discovered how to make compound lenses that didn't produce the spuriously coloured images of single lenses. The implementation was patented and this opened the way for Dollond's optical instruments to outstrip the performance of all others. Their superiority was recognised at home and abroad. Others followed when the patent expired. The technique also opened the way to produce larger telescopes, the telescope being the most prestigious instrument of many makers, the instrument that both sold for the largest price and attracted the custom of the really rich. There are good reasons why larger telescopes are better than smaller ones. However, the new lenses required a new kind of glass and to take up Agnes Clerke's words "*the crushing excise duty imposed upon glass by the financial unwisdom of the Government, both limited its production, and, by rendering experiments too costly for repetition, barred its improvement.*" Effectively they starved the geese that laid the golden eggs. This let the initiative in the scientific instrument trade pass to France and Germany, allowing makers who were well behind to not only catch up but surpass the English firms. From 1825 to 1830 Michael Faraday, no less, the supreme experimenter of his day, spent several years investigating how to produce new optical glasses with the right refractive and mechanical properties to help get the English lens industry, and other glass-based industries, back into an internationally competitive state. He wasn't brilliantly successful. The excise duty on glass wasn't removed until 1845.

This lesson from history has been learnt. The British scientific instrument industry did survive as one of the leading players not only in the 19th century but through the first half of the 20th century. Firms like *Grubb Parsons* in Newcastle upon Tyne, *Taylor, Taylor & Hobson* in Leicester, *Cooke, Troughton & Simms* of York, *The Cambridge Scientific Instrument Company* in Cambridge and London, *H. Tinsley* in London and many other UK firms made instruments that were the best in the world in the first half of the 20th century and beyond. The University's scientific instrument collection is lucky to have many examples of the craftsmanship of these firms. My main point here, though, is that scientific instrument production is no longer a minority interest of society. Less than three centuries ago most of the world's commercial scientific instruments were made in one of 3 countries. Now it is a multi-billion pound global industry that needs a high level of scientific expertise, of innovation and sophisticated manufacturing capability.

Civilisation

And so to my final point this evening. Those in the audience of about my age may remember the hugely popular TV series of 1969 that the museum director Sir Kenneth Clark wrote and presented, called *Civilisation: a personal view*. I can't recall any mention of scientific instruments in Clark's overview of civilisation. It was a series about Western Art. There



were a few pictures of grandiose 19th century engineering achievements; that's all the technology. Clark approvingly quoted Ruskin "*Great nations write their autobiographies in three manuscripts, the book of their deeds, the book of their words and the book of their art*".

My personal view is that art can reflect aspects of civilisation but what has really made us civilised in the past few centuries is knowledge gained of our surroundings on all scales, from the atomic to the cosmological, real knowledge about the distant past as well as the present, and the accompanying understanding of how nature and the environment in all their grandeur work. That knowledge is far from complete but it is hugely greater now than it used to be. Acquiring that knowledge has been a journey of centuries and the most important artefacts on that journey accompanying the human brains of our predecessors have not been artists' brushes or sculptor' chisels but instruments of science. Scientific instruments have created much of the civilisation we know today. Many people might have disputed this view in the past; I think many people will agree with this view in the future.

To finish on a more parochial note: the University of Aberdeen has an exceptional collection of historical scientific instruments dating from the second quarter of the 18th century. It is a collection of recognised international importance. Over two centuries, tens of thousands of

influential graduates have been taught some science using scientific instruments or seen them used in demonstrations. Nowadays, science students are exposed more to computers than instruments and the message isn't so obvious that science progresses mainly through the use of instruments. It does.

Nancy Pelosi's assertion that what is important now is "*SCIENCE, science, science and science*" is a message that will be repeated many times by others. Our historic instruments have huge social relevance as well as an obvious relevance to the history of science. Putting more of them on public display is a matter of economics and a matter of changing perceptions of their importance. I can't do much about the economics but I've been pleased to have this opportunity to say something about their social relevance. Our instruments are not just the heritage of the University; they are everyone's heritage.

JSR